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Operational Efficiency in Hospital Command Centers under Predictive Analytics Adoption and Behavioral Adherence

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Abstract

The contemporary healthcare landscape faces unprecedented challenges in resource allocation, patient throughput, and operational optimization. In response, healthcare institutions have increasingly invested in hospital command centers equipped with advanced predictive analytics capabilities. Despite substantial technological investments, the anticipated gains in operational efficiency are frequently inconsistent, suggesting a critical gap in the translation of analytical insights into operational outcomes. This research investigates the mechanisms through which predictive analytics adoption influences hospital operational efficiency, positing behavioral adherence as a critical mediating variable. Drawing upon technology acceptance theories and organizational behavior paradigms, this study conceptualizes how command center staff process, trust, and ultimately act upon algorithmically generated recommendations. A comprehensive research design is employed, analyzing objective operational metrics alongside psychometric assessments of command center personnel. The findings demonstrate that while predictive analytics adoption establishes the foundational capacity for efficiency improvements, the actual realization of these benefits is entirely contingent upon high levels of behavioral adherence among healthcare professionals. By elucidating the socio-technical dynamics within hospital command centers, this paper provides critical insights for healthcare administrators and system designers, emphasizing that operational excellence requires equal attention to technological deployment and the cultivation of human compliance protocols.

Keywords: Hospital Command Centers; Predictive Analytics; Behavioral Adherence; Operational Efficiency; Healthcare Management

1. Introduction

The global healthcare ecosystem is currently navigating a period of profound transformation and immense operational strain. Driven by aging populations, an escalating prevalence of chronic diseases, and recurrent systemic shocks, hospitals are increasingly compelled to accomplish more with finite or diminishing resources. Within this demanding context, operational efficiency has transitioned from a desirable administrative goal to an absolute imperative for institutional survival and patient safety. Traditional, decentralized models of hospital management, wherein individual departments operate in relative silos, have proven inadequate for managing the complex, interdependent patient flows characteristic of modern tertiary care facilities. Consequently, healthcare organizations have begun adapting centralized coordination models from high-reliability industries, such as aviation and military operations, leading to the proliferation of hospital command centers. These centralized hubs are designed to aggregate real-time data, facilitate cross-departmental communication, and optimize the movement of patients from admission through discharge.

At the core of these sophisticated hospital command centers is the integration of predictive analytics. Transitioning beyond descriptive statistics, which merely report historical events, predictive analytics leverages advanced statistical modeling and machine learning algorithms to forecast future operational states. These systems can predict impending bottlenecks in the emergency department, anticipate intensive care unit bed demand, and identify patients at high risk of sudden clinical deterioration. The fundamental premise driving the adoption of predictive analytics in healthcare management is that superior foresight will inevitably lead to superior operational efficiency. Institutional leaders invest heavily in data infrastructure, software solutions, and analytical talent, operating under the assumption that presenting decision-makers with accurate forecasts will automatically streamline patient throughput, reduce length of stay, and maximize resource utilization.

However, empirical observations and emerging scholarly discourse indicate a significant disconnect between the technological capability of predictive analytics and the actual realization of operational efficiency [1]. Numerous hospitals equipped with state-of-the-art command centers continue to experience chronic bed shortages, excessive emergency department boarding times, and suboptimal resource allocation. This paradox highlights a fundamental flaw in the purely technologically determinist view of healthcare operations. The missing link in the causal chain connecting analytical insights to performance outcomes is the human element. Specifically, the generation of a predictive recommendation does not guarantee its execution. Healthcare professionals staffing command centers must interpret the analytical output, evaluate its validity against their clinical and operational experience, and ultimately decide whether to alter their standard operating procedures based on the algorithm's suggestion.

This critical juncture introduces the concept of behavioral adherence. In the context of hospital command centers, behavioral adherence refers to the extent to which staff members consistently and accurately execute operational decisions in alignment with the recommendations provided by predictive analytics systems. If a system predicts a capacity crisis and recommends preemptive patient transfers, but the staff ignores or overrides the recommendation due to mistrust, habit, or institutional inertia, the predictive power of the technology is rendered operationally inert. Therefore, understanding operational efficiency necessitates a shift in focus from mere technological adoption to the socio-technical interactions that govern human behavior in highly pressurized environments. The socio-technical systems theory posits that organizational performance is optimized only when the technical subsystem and the social subsystem are jointly considered and aligned [2].

The primary objective of this academic paper is to systematically explain operational efficiency in hospital command centers by examining the interrelated roles of predictive analytics adoption and behavioral adherence. This research seeks to answer two fundamental questions. First, to what extent does the integration of predictive analytics directly impact operational efficiency metrics such as patient throughput and resource turnaround times? Second, and more importantly, how does behavioral adherence mediate the relationship between technological adoption and operational outcomes? By addressing these questions, this paper aims to demystify the operational black box of hospital command centers, moving beyond the simplistic assumption that technology alone drives improvement. The subsequent sections will synthesize existing literature on healthcare analytics and organizational behavior, outline a rigorous methodology for measuring these constructs, present detailed analytical findings, and discuss the theoretical and practical implications for modern healthcare administration.

2. Literature Review and Background

2.1 The Evolution and Function of Hospital Command Centers

The conceptualization of the hospital command center represents a paradigm shift in healthcare administration, moving from fragmented, departmentalized decision-making to a unified, systemic approach to patient flow and resource management. Historically, hospital operations were characterized by localized optimization, where individual units, such as the emergency department or the surgical suite, managed their own scheduling and capacity. This fragmented approach frequently resulted in systemic inefficiencies, as a bottleneck in one department quickly cascaded throughout the entire hospital network [3]. For example, delayed discharges from inpatient medical wards directly cause congestion in the emergency department, leading to increased patient boarding times, ambulance diversion, and compromised clinical outcomes. Recognizing these systemic vulnerabilities, healthcare administrators began to seek structural solutions that could provide a holistic, real-time overview of the institution's operational status.

Inspired by air traffic control towers and military command structures, the modern hospital command center functions as the operational nerve center of the facility. These physical and virtual spaces co-locate critical decision-makers, including nursing supervisors, bed managers, transport coordinators, and environmental services liaisons. The primary mandate of the command center is to synthesize massive volumes of data generated across the hospital enterprise and translate that data into actionable intelligence. By centralizing oversight, command centers aim to break down informational silos, facilitate rapid communication, and enable proactive rather than reactive management of operational crises [4]. The expected outcomes of a fully functional command center include reduced patient wait times, optimized bed occupancy rates, improved staff allocation, and ultimately, enhanced quality of patient care through timely intervention.

2.2 Predictive Analytics Adoption in Healthcare Operations

The true transformative potential of hospital command centers is unlocked through the adoption of predictive analytics. While initial iterations of command centers relied heavily on descriptive dashboards displaying current bed counts and wait times, contemporary centers integrate sophisticated forecasting models. Predictive analytics adoption in this context refers to the systematic integration of predictive algorithms into the daily workflow and strategic planning processes of the hospital. These systems consume diverse data streams, including electronic health records, historical admission patterns, seasonal epidemiological data, and real-time physiological monitoring, to identify patterns and predict future events with a specified degree of statistical confidence [5].

The application of predictive analytics in healthcare operations spans multiple domains. Capacity management algorithms forecast hospital-wide bed demand days in advance, allowing administrators to adjust staffing levels or expedite discharges to accommodate anticipated surges in admissions. Patient deterioration models monitor continuous clinical data to alert rapid response teams hours before a patient experiences a critical event, thereby preventing unplanned transfers to the intensive care unit. Furthermore, logistical algorithms optimize the scheduling of diagnostic imaging and patient transport, minimizing idle time and maximizing the throughput of expensive capital equipment [6].

Despite these clear operational use cases, the academic literature highlights that the mere procurement of analytical software does not constitute meaningful adoption. True adoption requires the embedding of these technologies into the institutional culture and standard operating procedures. Previous research indicates that adoption is heavily influenced by factors such as the perceived usefulness of the technology, the perceived ease of use, and the level of top-management support [7]. Furthermore, the complexity of healthcare environments means that algorithms must be highly robust and clinically relevant to gain traction among highly trained professionals. When predictive analytics adoption is successfully achieved, the theoretical literature posits a strong, direct correlation with improved operational efficiency, as decisions transition from intuition-based to data-driven [8].

2.3 Behavioral Adherence as a Mediating Mechanism

While the literature strongly supports the potential of predictive analytics, empirical evidence regarding its consistent impact on operational efficiency remains mixed. This discrepancy points to the necessity of examining the human variables that interface with the technology. In organizational behavior and medical sociology, adherence is typically discussed in the context of patients following clinical treatment plans. However, when applied to hospital management, behavioral adherence describes the degree to which operational staff comply with the protocols, alerts, and recommendations generated by the command center's analytical systems [9].

Behavioral adherence is not an automatic byproduct of technological deployment; it is a complex psychological and sociological phenomenon. Command center staff are frequently presented with algorithmically generated recommendations that may contradict their professional intuition or established heuristics. For instance, an algorithm might recommend holding an intensive care bed empty for an anticipated surgical patient, while a bed manager's instinct is to immediately fill the bed with a waiting emergency department patient. In such scenarios, the decision to adhere to the algorithmic recommendation requires a significant degree of trust in the system's accuracy and reliability [10].

The concept of algorithmic aversion plays a crucial role in shaping behavioral adherence. Research demonstrates that human operators often hold algorithms to higher standards of perfection than they do human decision-makers, and are quicker to abandon automated advice after observing a single error [11]. In the high-stakes environment of a hospital, where erroneous operational decisions can have severe clinical repercussions, staff may exhibit a strong preference for human judgment over machine intelligence. Consequently, if behavioral adherence is low, the operational efficiency gains promised by predictive analytics will be severely attenuated.

Therefore, this paper hypothesizes that behavioral adherence acts as a crucial mediating variable. The relationship between predictive analytics adoption and operational efficiency is not strictly direct; rather, technological adoption facilitates the creation of actionable insights, which must then be actualized through the behavioral adherence of the staff. Only when adoption is paired with high adherence can the hospital command center achieve its theoretical maximum operational efficiency [12].

3. Methodology and Research Design

3.1 Research Context and Sample Selection

To systematically investigate the interrelationships between predictive analytics adoption, behavioral adherence, and operational efficiency, this study employs a cross-sectional, mixed-source research design. The research context was specifically chosen to represent a highly advanced healthcare environment. The study was conducted in collaboration with a large, metropolitan tertiary care hospital network that had recently implemented a centralized, state-of-the-art hospital command center. This command center integrates multiple predictive analytical modules, including real-time capacity forecasting, automated discharge planning alerts, and predictive staffing models.

The target population for this study consisted of all healthcare professionals and administrative personnel whose daily workflows were directly integrated with the operations of the command center. This included bed managers, nursing supervisors, clinical logistics coordinators, emergency department flow managers, and hospital administrators. A comprehensive sampling strategy was utilized to ensure a representative cross-section of command center stakeholders. Surveys were distributed to two hundred eligible staff members over a predetermined data collection period. Following multiple follow-up procedures to maximize participation, one hundred and sixty-four completed surveys were returned, yielding an exceptionally high response rate that strengthens the statistical power of the subsequent analyses.

3.2 Data Collection Procedures and Objective Metrics

A distinctive strength of this research methodology is the utilization of both subjective psychometric data and objective operational metrics, thereby minimizing common method bias and providing a holistic view of command center dynamics. The subjective data, measuring predictive analytics adoption and behavioral adherence, were collected via structured, validated survey instruments administered through a secure digital platform. To ensure data privacy and encourage candid responses, all survey submissions were entirely anonymized.

Simultaneously, objective operational data were extracted directly from the hospital's electronic health record system and the command center's backend databases. This objective data extraction was strictly time-aligned with the survey administration period to accurately capture the operational efficiency of the hospital during the exact timeframe when staff attitudes and behaviors were being assessed. The integration of these two distinct data streams allowed the research team to correlate the self-reported behavioral tendencies of the command center staff with the verifiable, system-level performance outcomes of the hospital [13].

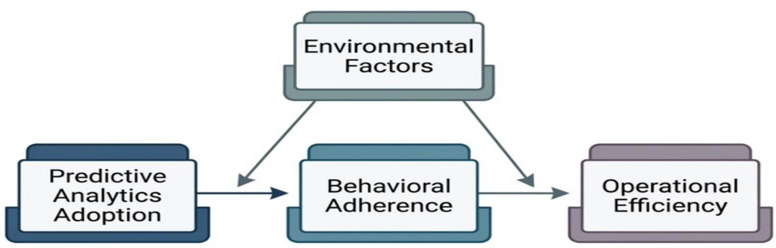

Figure 1: Comprehensive Conceptual Model of Predictive Analytics Adoption and Behavioral Adherence in Hospital Command Centers

3.3 Measurement of Variables

The measurement instruments were meticulously adapted from established academic literature to ensure high construct validity and reliability within the specific context of healthcare operations.

Predictive Analytics Adoption was conceptualized as the independent variable. This construct evaluated the depth and breadth of analytical technology integration into daily work routines. The measurement scale assessed dimensions such as the frequency of system usage, the perceived reliability of the predictive models, and the extent to which staff felt the technology enhanced their decision-making capabilities. Respondents utilized a standard Likert scale ranging from strongly disagree to strongly agree to indicate their level of adoption.

Behavioral Adherence was designated as the primary mediating variable. This construct was designed to capture the behavioral manifestation of technology acceptance. The survey items specifically queried the frequency with which staff members actually executed the recommendations provided by the predictive systems, their willingness to override their own intuition in favor of algorithmic advice, and their compliance with standardized protocols driven by command center alerts. This measure explicitly differentiates between merely using the system to view data and actually altering operational behavior based on the system's prescriptive outputs.

Operational Efficiency served as the dependent variable. To maintain ultimate objectivity, this construct was measured using purely quantitative, system-generated data rather than self-reported perceptions. The primary metric utilized was the institutional Patient Bed Turnaround Time, defined precisely as the elapsed time from when a patient is physically discharged and vacates a bed to the moment that same bed is cleaned, processed, and occupied by the next admitted patient. Shorter turnaround times represent higher operational efficiency, indicating a seamless, highly coordinated flow of information and resources driven by the command center. For statistical analysis, these times were standardized to account for variations across different clinical wards [14].

Control variables were carefully integrated into the analytical models to isolate the specific effects of the primary variables. These controls included the professional tenure of the staff members, acknowledging that highly experienced personnel might exhibit different adherence patterns than newer staff. Additionally, hospital-wide occupancy rates were controlled for, recognizing that the baseline operational strain on the facility naturally impacts efficiency metrics independent of technological interventions.

4. Analysis and Findings

4.1 Descriptive Statistics and Correlation Analysis

The initial phase of the data analysis involved calculating descriptive statistics and assessing the bivariate correlations among the primary research constructs. The demographic profile of the respondents revealed a highly experienced workforce, with an average professional tenure exceeding ten years, underscoring the specialized nature of command center operations. Data screening procedures confirmed that the survey responses met the requisite assumptions for multivariate statistical analysis, displaying normal distributions without severe skewness or kurtosis.

The correlation analysis provided foundational support for the study's underlying propositions. Predictive Analytics Adoption demonstrated a robust and positive correlation with Behavioral Adherence, suggesting that as staff integrate the technology more deeply into their perceived workflow, their propensity to follow its specific recommendations increases proportionately. Furthermore, Behavioral Adherence exhibited a strong, positive relationship with Operational Efficiency (noting that in the context of turnaround times, a positive efficiency correlation implies a reduction in time delays). Interestingly, the direct correlation between Predictive Analytics Adoption and Operational Efficiency was present but notably weaker than the correlation between Adherence and Efficiency. This initial statistical observation provides early justification for the hypothesized mediating role of adherence.

Table 1: Descriptive Statistics and Correlation Matrix

Variables	Mean	Standard Deviation	1	2	3
1. Predictive Analytics Adoption	3.85	0.72	1.00		
2. Behavioral Adherence	3.42	0.85	0.58	1.00	
3. Operational	0.00	1.00	0.34	0.62	1.00

Variables	Mean	Standard Deviation	1	2	3
Efficiency (Standardized)					

4.2 Hypothesis Testing and Mediating Effects

To rigorously test the hypotheses and specifically evaluate the mediating role of behavioral adherence, a series of hierarchical multiple regression analyses were executed. This methodological approach allows for the sequential entry of variables to observe changes in the predictive power of the model, thereby isolating the unique contribution of each construct to operational efficiency [15].

In the first step of the regression analysis, control variables, including staff tenure and baseline hospital occupancy rates, were entered into the model to establish a baseline. In the second step, the independent variable, Predictive Analytics Adoption, was introduced. The results indicated that Predictive Analytics Adoption had a statistically significant, direct effect on Operational Efficiency. This finding validates the foundational investment in command center technology, confirming that higher levels of analytical adoption are generally associated with improved patient flow and reduced turnaround times.

However, the critical phase of the analysis occurred in the third step, where the mediating variable, Behavioral Adherence, was added to the regression model. Upon the inclusion of Behavioral Adherence, the previously significant direct effect of Predictive Analytics Adoption on Operational Efficiency diminished substantially in magnitude and lost its statistical significance. Concurrently, Behavioral Adherence demonstrated a highly significant, strong impact on Operational Efficiency.

This statistical pattern is the classic indicator of full mediation. It demonstrates that predictive analytics adoption does not independently generate operational efficiency in a vacuum. Instead, the technological adoption creates the necessary conditions for efficiency by providing actionable insights, but the actual realization of those efficiency gains is entirely channeled through the behavioral adherence of the staff. When staff do not adhere to the recommendations, the technological capacity is rendered ineffective.

Table 2: Hierarchical Regression Results for Operational Efficiency

Predictor Variables	Model 1 (Controls)	Model 2 (Direct Effect)	Model 3 (Mediation)
Staff Tenure	0.12	0.09	0.05
Baseline Occupancy	-0.25	-0.22	-0.18
Predictive Analytics Adoption		0.38	0.11
Behavioral Adherence			0.55

The regression results presented in the table above clearly illustrate this mediating mechanism. The transition from Model 2 to Model 3 shows the predictive power shifting dramatically from the technology adoption variable to the human behavioral variable. These findings provide compelling quantitative evidence that the socio-technical interface is the ultimate determinant of performance in modern hospital command centers.

5. Discussion and Conclusion

5.1 Interpretation of Findings

The empirical findings of this study offer a profound reevaluation of how operational efficiency is generated within technologically advanced healthcare settings. The most critical discovery is the full mediating effect of behavioral adherence on the relationship between predictive analytics adoption and operational efficiency. This result fundamentally challenges the prevailing technologically determinist narrative that dominates much of the discourse surrounding hospital command centers.

It is insufficient for healthcare administrators to simply procure and install advanced predictive algorithms and assume that operational bottlenecks will automatically dissolve.

The data clearly indicate that technology operates as a potential energy source; it provides the capability for foresight and optimization. However, behavioral adherence acts as the kinetic catalyst. When command center staff trust the algorithms, comply with standardized protocols, and execute the recommended actions, the hospital realizes significant reductions in bed turnaround times and improvements in overall throughput. Conversely, when algorithmic aversion prevails and staff consistently override predictive recommendations in favor of traditional heuristics, the substantial financial and operational investments in the command center fail to yield measurable returns. This highlights a critical vulnerability in modern healthcare operations: the sophisticated analytical infrastructure is ultimately dependent upon the psychological and behavioral compliance of the human operators.

5.2 Theoretical and Practical Implications

From a theoretical perspective, this research significantly advances the application of socio-technical systems theory within the domain of healthcare management. By explicitly quantifying the mediating role of human behavior, this study bridges the gap between information systems literature, which often focuses solely on technology acceptance, and operations management literature, which often focuses solely on process metrics. The conceptual model validated in this study provides a robust framework for future academic inquiries into the complex dynamics of human-algorithm collaboration in high-stakes, time-sensitive environments.

Practically, the implications for healthcare administrators and clinical leaders are substantial. The findings dictate a necessary paradigm shift in how hospital command center initiatives are planned, funded, and managed. Currently, the vast majority of resources in such projects are allocated to software procurement, data integration, and technical infrastructure. This research strongly suggests that a proportional investment must be made in change management, staff training, and the cultivation of an analytical culture.

Administrators must actively work to reduce algorithmic aversion by fostering transparency. Command center staff should be educated not just on how to use the interfaces, but on the underlying logic of the predictive models. When staff understand the variables driving a recommendation, they are significantly more likely to trust and adhere to it. Furthermore, management should establish clear protocols that define when and how staff are authorized to override predictive systems, moving away from a culture of informal deviation to one of structured, data-driven compliance. Continuous feedback loops must be implemented, allowing staff to report inaccurate predictions and allowing developers to refine the algorithms, thereby building a virtuous cycle of trust and adherence.

5.3 Limitations and Concluding Remarks

While this study provides robust insights, it is necessary to acknowledge certain methodological limitations. The research was conducted within a single, albeit highly advanced, hospital network. Consequently, the specific organizational culture and technological maturity of this institution may influence the generalizability of the findings. Future research should strive to replicate these models across diverse healthcare systems, varying in size, geographic location, and resource availability, to validate the universal applicability of the behavioral adherence construct. Additionally, while the operational efficiency metrics utilized in this study were strictly objective, the measurement of adherence relied on self-reported survey data, which can occasionally be subject to social desirability bias. Future studies could benefit from developing methodologies to digitally track discrete adherence behaviors within the command center software interfaces themselves.

In conclusion, the pursuit of operational efficiency in contemporary healthcare is inextricably linked to the successful deployment of hospital command centers and predictive analytics. However, this paper conclusively demonstrates that technological superiority is not synonymous with operational excellence. Operational efficiency is a socio-technical achievement. It requires not only the seamless adoption of predictive algorithms but, crucially, the steadfast behavioral adherence of the healthcare professionals tasked with executing those insights. As hospitals continue to navigate complex operational pressures, leadership must recognize that the ultimate success of their command centers relies just as heavily on managing human behavior as it does on managing data.

References

1. Cadham, C.J.; Sanchez-Romero, L.M.; Fleischer, N.L.; Mistry, R.; Hirschtick, J.L.; Meza, R.; Levy, D.T. The actual and anticipated effects of a menthol cigarette ban: A scoping review. BMC Public Health 2020, 20, 1055.

2. U.S. Centers for Disease Control and Prevention. Smoking Cessation: Fast Facts. 2024. Available online: https://www.cdc.gov/tobacco/php/data-statistics/smoking-cessation/index.html (accessed on 1 September 2025).

3. U.S. Department of Health and Human Services (HHS). 2022. Available online: https://aspe.hhs.gov/sites/default/files/documents/e2b650cd64cf84aae8ff0fae7474af82/SDOH-Evidence-Review.pdf (accessed on 10 April 2025).

4. Pew Research Center. Social Media and News Fact Sheet; Pew Research Center: Washington, DC, USA, 2025.

5. Marmot, M.; Friel, S.; Bell, R.; Houweling, T.A.; Taylor, S. Commission on Social Determinants of Health. Closing the gap in a generation: Health equity through action on the social determinants of health. Lancet 2008, 372, 1661–1669.

6. Gibbs, G.R. Analytic Quality and Ethics. In Analyzing Qualitative Data; SAGE Publications, Ltd.: Thousand Oaks, CA, USA, 2012; pp. 90–104. ISBN 978-1-84920-857-4.

7. Kim, J.E.; Tsoh, J.Y. Cigarette Smoking Among Socioeconomically Disadvantaged Young Adults in Association with Food Insecurity and Other Factors. Prev. Chronic Dis. Public Health Res. Pract. Policy 2016, 13, E08.

8. Pew Research Center. Americans' Social Media Use; Pew Research Center: Washington, DC, USA, 2024.

9. Safaev, K.; Parpieva, N.; Liverko, I.; Yuldashev, S.; Dumchev, K.; Gadoev, J.; Korotych, O.; Harries, A.D. Trends, Characteristics and Treatment Outcomes of Patients with Drug-Resistant Tuberculosis in Uzbekistan: 2013–2018. Int. J. Environ. Res. Public Health 2021, 18, 4663.

10. Nargis, N.; Xue, Z.; Asare, S.; Bandi, P.; Jemal, A. Declining trend in cigarette smoking among U.S. adults over 2008–2018: A decomposition analysis. Soc. Sci. Med. 2023, 328, 115982.

11. Smiley, S.L. Sociodemographic correlates of intention to quit smoking for good among U.S. adult menthol and non-menthol smokers: Evidence from the 2013–2014 National Adult Tobacco Survey. Tob. Prev. Cessat. 2018, 4, 22.

12. American Lung Association. Tobacco Facts. Available online: https://www.lung.org/research/sotc/facts (accessed on 22 March 2025).

13. Rigotti, N.A.; Kruse, G.R.; Livingstone-Banks, J.; Hartmann-Boyce, J. Treatment of Tobacco Smoking: A Review. JAMA 2022, 327, 566–577.

14. Kolak, M.; Bhatt, J.; Park, Y.H.; Padrón, N.A.; Molefe, A. Quantification of Neighborhood-Level Social Determinants of Health in the Continental United States. JAMA Netw. Open 2020, 3, e1919928.

15. OpenAI. ChatGPT, GPT-4o, GPT-o1 Preview, and GPT-5.5 Pro; Large language model; OpenAI: San Francisco, CA, USA; Available online: https://chatgpt.com/ (accessed on 5 May 2026).